

Yellow Sticky Trap Catches of Parasitoids of *Bemisia tabaci* (Hemiptera: Aleyrodidae) in Vegetable Crops and Their Relationship to In-Field Populations

KIM A. HOELMER¹ AND ALVIN M. SIMMONS²

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ABSTRACT We examined the relationship of yellow sticky trap captures of *Bemisia tabaci* (Gennadius) biotype B parasitoids to the local population of parasitoids as measured by leaf samples of parasitized whiteflies and mass release of parasitoids. Traps were placed in experimental collard and cowpea field plots in Charleston, SC, and in commercial organic fields of spring cantaloupe and watermelon in the Imperial Valley, CA. The exotic parasitoid *Eretmocerus emiratus* Zolnerowich and Rose was released in Imperial Valley fields to ensure parasitoid populations would be present. *Bemisia* adults were trapped in the greatest numbers on the upper surface of horizontally oriented sticky traps in melon fields. In contrast, the lower trap surfaces consistently captured more *Eretmocerus* than upper surfaces. Female parasitoids were trapped in greater numbers than males, especially on the lower trap surfaces. Progeny of released exotic *Eretmocerus* greatly outnumbered native *E. eremicus* Rose and Zolnerowich and *Encarsia* spp. on traps. Throughout the season, the trend of increasing numbers of *Eretmocerus* on traps paralleled the increase in numbers of whiteflies. Over the season, 23–84% of all *B. tabaci* fourth instars were visibly parasitized by *Eretmocerus*. The numbers of *Eretmocerus* caught by traps in cantaloupe were similar in trend to numbers on leaf samples in melons, but not with those in watermelon, where whitefly populations were lower. Parasitoid numbers were low in collard and cowpea samples, and no trend was observed in numbers of parasitoids captured on traps and numbers on leaves for these two crops. Overall, there were no significant correlations between sticky trap catches of parasitoids and numbers of parasitized whiteflies on leaf samples in any test fields. Nevertheless, sticky traps placed within crops may be useful for observing trends in whitefly parasitoid populations at a particular site and for detecting parasitoids at specific locations.

KEY WORDS *Bemisia tabaci* biotype B, sweetpotato whitefly, biological control, *Eretmocerus* spp., *Encarsia* spp.

The sweetpotato whitefly, *Bemisia tabaci* (Gennadius) biotype B (=silverleaf whitefly, *B. argentifolii* Bellows and Perring), feeds on and damages numerous crops and ornamentals on a global scale, and it is especially problematic in the southern United States (Gonzalez et al. 1992, Schuster et al. 1996, Riley and Ciomperlik 1997). Vegetables and melons are among the crops damaged by this pest. Yellow sticky traps are widely used to monitor for the presence of whiteflies (Gerling and Horowitz 1984, Byrne et al. 1995, Riley and Ciomperlik 1997) and have also been used to survey for the presence and relative abundance of parasitoids and predators of whiteflies (Dowell and Cherry 1981, Udayagiri et al. 1997) and other pests and

their natural enemies (Neuenschwander 1982, Esker et al. 2004, Musser et al. 2004). Aphelinids in the genera *Encarsia* and *Eretmocerus* are the most prevalent parasitoids of *Bemisia* (Gerling 1990, Polaszek et al. 1992, De Barro 1995). We previously reported that native *Encarsia* and *Eretmocerus* parasitoids of *B. tabaci* are captured by yellow sticky cards placed in field crops (Hoelmer et al. 1998, Simmons 1998, Simmons and Jackson 2000). Parrella et al. (1991) also reported that yellow traps caught large numbers of *Encarsia formosa* Gahan that had been released against *B. tabaci* in greenhouses. Moreover, observations during quarantine rearing and mass culture of various species of exotic *Encarsia* and *Eretmocerus* imported to the United States for biological control of *B. tabaci* indicated that they are also attracted to yellow sticky traps (J. Goolsby, personal communication).

Although a few studies have reported correlations between populations of whiteflies and their parasitoids with surveys using yellow sticky cards (Riley and Ciomperlik 1997, Qiu and Ren 2006), there is relatively little information that relates the number of trapped

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¹ Corresponding author: USDA-ARS, Beneficial Insect Introduction Research Unit, 501 S. Chapel St, Newark, DE 19713 (e-mail: kim.hoelmer@ars.usda.gov).

² USDA-ARS, U.S. Vegetable Laboratory, 2700 Savannah Highway, Charleston, SC 29414.

whitefly parasitoids on sticky cards to population trends in the adjacent or surrounding field crops. Therefore, we conducted several studies to examine the relationship of yellow sticky trap captures of parasitoids of *B. tabaci* to the population of parasitoids as measured by leaf samples of parasitized whiteflies and mass release of parasitoids.

Materials and Methods

Yellow sticky traps (Olson Products, Medina, OH) were used to monitor populations of insects in fields of collard, *Brassica oleracea* L. variety *acephala* DC (summer-fall 1997), and cowpea (southern pea), *Vigna unguiculata* L. Walp. ssp. *unguiculata* (summer-fall 1998), on an experimental farm in Charleston, SC, and in commercial organic fields of cantaloupe, *Cucumis melo* L., and watermelon, *Citrullus lanatus* (Thunberg) Matsumura and Nakai variety *lanatus* in the Imperial Valley, CA (spring 1998).

Source of Parasitoids. Observations on parasitoids in South Carolina were based on the capture of naturally occurring *Encarsia* and *Eretmocerus* spp. in local populations present on the USDA-ARS research farm in Charleston. In California, we supplemented naturally occurring parasitism by the native *Eretmocerus eremicus* Rose and Zolnerowich (formerly *E. sp. nr. californicus*) in the Imperial Valley because populations of *E. eremicus* are low in early spring when melons are planted (K.A.H., unpublished data). Approximately 1.6 million exotic *E. emiratus* Zolnerowich and Rose were released during a 6-wk period in two commercial cantaloupe and watermelon fields used as study sites in the Imperial Valley. The parasitoids were originally derived from insectary culture M95104 ex United Arab Emirates maintained at the USDA APHIS PPQ Mission Biological Control Center (now the APHIS PPQ CPHST Laboratory), Edinburg, TX. This species was mass-produced by APHIS in the Imperial Valley for release and establishment in California as part of an ongoing classical biological control program against *B. tabaci* (Hoelmer and Kirk 1999, Goolsby et al. 2005, Roltsch et al. 2007). Supplemented parasitoids were distributed within the fields as pupae in 15-ml plastic cups. Approximately 15,000 *E. emiratus* pupae were placed into each cup (determined by weight based on the provider's estimate of $\approx 23,000$ pupae/g) and distributed in the fields just as adult emergence in each rearing lot was beginning so that the exposure time of pupae to adverse weather and predators was minimized. The cups were placed on the ground at the base of plants under the crop canopy. Releases were made when first- and second-instar *B. tabaci* were detected in field surveys, because our laboratory observations showed that female wasps would oviposit under all four instars (unpublished data). Releases were continued for 3–6 wk and were stopped a week before the first placement of yellow sticky traps.

Field samples for determination of parasitism in California and South Carolina were collected by taking random samples of leaves containing late fourth-instar or emerging adult whiteflies because parasitism

is most evident among parasitized whitefly nymphs of this age class (Gould and Naranjo 1999). Traps and corresponding leaf samples were collected weekly and returned to the laboratory where numbers of parasitized whiteflies on leaf samples and numbers of adult whitefly and parasitoids were determined with the aid of a binocular stereoscopic microscope. New traps were set out whenever used traps were collected, so that traps were always present in the field for the duration of the sampling period.

Cantaloupe and Watermelon, Imperial Valley, CA. Two study sites consisted of a 5.3-ha cantaloupe field and a 7.3-ha watermelon field located ≈ 7 km south of Holtville, CA, in Imperial County. No pesticide treatments were applied in these commercial fields, because they were designated as organic. Both fields were planted in early spring 1998. Whitefly populations were monitored to determine when immature whiteflies were present. A total of $\approx 707,000$ parasitoid pupae were distributed in the cantaloupe field on six dates (28,000, 90,000, 93,500, 175,000, 20,500, and 300,000 were set out on 25 and 31 March and 1, 3, 9, and 23 April 1998, respectively). A total of $\approx 884,000$ parasitoid pupae were distributed in the watermelon field on six dates (160,000, 50,500, 93,500, 175,000, 205,000, and 200,000, respectively, were set out on 17 and 20 March and 1, 3, 9, and 23 April 1998, respectively). Pupae in plastic cups were placed in a grid pattern of point releases within a 100 by 100-m block in the center of the field. Random checks during the following week were made to verify that emergence had largely been completed. The first set of sticky traps were placed into the field within and immediately surrounding this central block when emergence was first noted for whitefly pupae, which was on 27 April for both fields. Double-sided yellow sticky traps were cut into pieces of 15.25 by 15.25 cm. Twenty traps were placed into each field, with four to five traps per row, equally spaced, with at least two rows between each row containing traps. Traps were attached to stakes placed between plants on row beds. Because *B. tabaci* is more readily trapped with horizontally oriented traps (i.e., parallel with the ground) rather than traps oriented vertically (Gerling and Horowitz 1984, Lynch and Simmons 1993), our traps were attached to wire clips that held the cards horizontal to the ground at a height of 15 cm from the surface of the bed.

Samples of 20 entire leaves containing either late fourth-instar, emerging, or mostly emerged whiteflies and visibly parasitized pupae per field per week were randomly collected from plants interspersed within the trap area. Counts of unparasitized and parasitized fourth-instar whiteflies ("nymphs") and nymphs from which whiteflies had emerged were made in the laboratory with a binocular microscope. Apparently unparasitized nymphs were turned over with a dissecting needle, and the presence or absence of *Eretmocerus* eggs was recorded. If eggs were found, the nymphs were recorded as parasitized, as were whitefly nymphs with visibly displaced mycetomes (indicating the presence of parasitoid larvae) and those containing *Eretmocerus* pupae and mummified whitefly nymphs

with *Eretmocer* emergence holes. Percentage parasitism was based on the number of parasitized whiteflies divided by the total number of parasitized and unparasitized whitefly fourth-instar nymphs. After the count, leaves were kept in the laboratory to allow parasitoids to emerge for species identification. Voucher specimens were retained for the author's collection (K.A.H.). The numbers of adult *B. tabaci* and adult parasitoids were counted on each sticky card and identified with the aid of a binocular microscope. Native and introduced *Eretmocer* were distinguished by morphological characters.

Collard, Charleston, SC. 'Georgian' variety collard was grown on black plastic mulch in a 0.8-ha field plot on 203-cm row spacing in Charleston in September 1997. Yellow sticky cards were placed in the field 1 wk after transplant of the collards. Twenty 16-cm² sticky cards were randomly set up throughout the field. No pesticide was used after the transplant except for a single application of Thuricide (*Bacillus thuringiensis*) before the sampling started; however, herbicides were used before the transplant. The sticky cards were placed horizontally 15 cm above ground. The cards were placed on inverted red clay pots and were replaced weekly with new cards from 23 September 1997 to 6 January 1998. The numbers of adult *B. tabaci* and adult *Encarsia* and *Eretmocer* were counted on each sticky card with the aid of a microscope. Samples of leaves with all stages of immature whiteflies were collected weekly to determine parasitism of whitefly nymphs, and they were held in the laboratory in sealed containers for insect emergence. From four to eight leaves were collected per week, and the numbers of parasitoids and whiteflies that emerged were counted. Percentage parasitism was based on the number of parasitoids that emerged relative to the total number of parasitoids and whitefly emergence.

Cowpea, Charleston, SC. Cowpea was planted into two fields (designated 8LW and 2F) in Charleston in July 1998. The fields were located 0.7 km apart, and each was ≈ 1 ha in size. Row spacing and mulch were the same as in the 1997 collard field test in Charleston, and no pesticides were used after the seeds were planted. On seedling emergence, yellow sticky cards were placed in the field plots as described in 1997. Throughout each field, 20 sticky cards were placed randomly. The sticky cards were retrieved after 4 d, and new cards were set up weekly from the time the first cards were set up from 28 July to 27 October. In addition, weekly leaf samples were taken from each plot. From 12 to 21 leaflets were collected on each sample date to determine the proportion of whitefly nymphs parasitized. The leaf samples were held in the laboratory in sealed containers for insect emergence. The numbers of parasitoids and whiteflies that emerged were counted. Percentage parasitism was based on the number of parasitoids that emerged relative to the total number of parasitoids and whitefly emergence.

Incidence of Capture in the Laboratory. An experiment was conducted in the laboratory in South Carolina to determine whether there were any differences

in the capture on sticky cards between native *Encarsia pergandiella* Howard and an undescribed native *Eretmocer* sp. (identifications by G. Zolnerowich, Kansas State University), between sexes of the *Eretmocer* sp., between *B. tabaci* females and *Eretmocer* females, and between sexes of *B. tabaci*. The tests were conducted in a laboratory rearing room at $25 \pm 1^\circ\text{C}$ and a photoperiod of 24:0 (L:D) h. Clear Plexiglas cages (45 cm wide by 45 cm long by 46 cm high) were illuminated by fluorescent lighting (40-W cool white and 40-W Vita-lite Power-twist; Duro-test, North Bergen, NJ; product no longer manufactured) that supplied ≈ 452 lux at sticky card height. A sticky card (5 cm²) was placed horizontally on an inverted red clay pot 15 cm from the bottom of the cage and located in the center of the cage. Adult *Eretmocer* sp. and *E. pergandiella* were collected from a greenhouse colony. The whiteflies in the colony originated from field-grown sweetpotato (*Ipomoea batatas* L.) in 1992 and were maintained on numerous vegetable plants as described by Simmons (1994). The *E. pergandiella* originated from a natural invasion of the colony in 1992. The *Eretmocer* sp. was also from a natural invasion first observed in the greenhouse colony in 1996. Parasitoids and whiteflies were individually aspirated into glass vials and inspected by microscope to determine their sex.

For each test, 15–20 individual insects of each sex per species (depending on the comparison) were released into each of four Plexiglas cages through a small hole drilled in the top center of each cage. After 24 h, the number of parasitoids of each species captured on the sticky cards was determined per cage. This test was repeated several times, resulting in total numbers for each comparison of 140 (*Encarsia* versus *Eretmocer* females), 640 (*Eretmocer* males versus females), 360 (*Eretmocer* females versus *B. tabaci* females), and 240 (*B. tabaci* males versus females). Observations showed that this method of dispensing the insects through the top of the cage did not result in significant capture immediately on introduction.

Data from the South Carolina studies were analyzed using SAS (SAS Institute 2002). Percentage data were subjected to arcsine transformation before analysis. Means were compared using the *t*-test. The California field data were analyzed with Statistix for Windows version 8 (Analytical Software 2003).

Results

Cantaloupe and Watermelon, Imperial Valley, CA. In spring melons, whitefly and parasitoid populations increased throughout the season and were more numerous in the cantaloupe field than in the watermelon field. As whitefly numbers increased into the season, *Bemisia* adults were trapped in increasingly greater numbers on the upper surface of sticky traps until the final sample date, when adult activity was reduced, although unparasitized fourth-instar whiteflies continued to increase in numbers on leaf samples (Fig. 1). In contrast, downward-facing trap surfaces consistently captured significantly more *Eretmocer* than

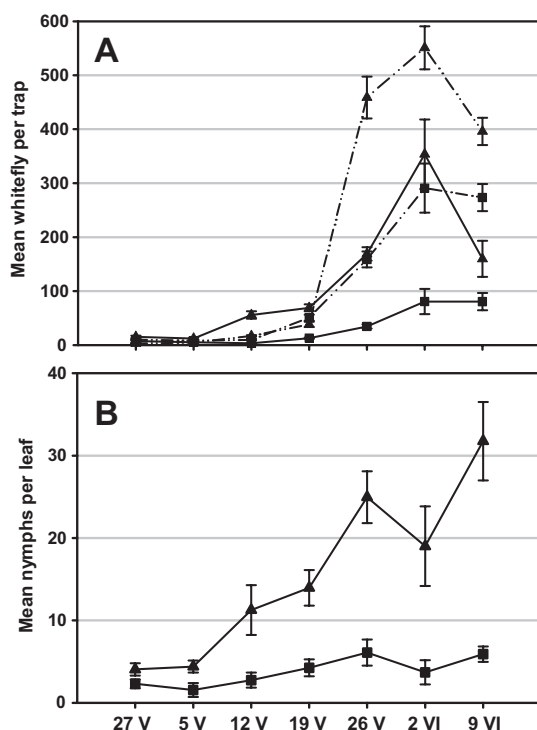


Fig. 1. (A) Mean numbers (\pm SEM) of *B. tabaci* adults trapped on upper (dashed lines) and lower (solid lines) surfaces of yellow sticky traps in cantaloupe (\blacktriangle) and watermelon (\blacksquare) fields, Imperial Valley, CA, in spring of 1998. (B) Mean number (\pm SEM) of unparasitized *B. tabaci* fourth instars on leaf samples collected concurrently with traps in cantaloupe and watermelon.

upward-facing traps in both cantaloupe and watermelon (Fig. 2). Excluding the first sample date (when very low trap numbers disproportionally skewed comparisons), the mean trap bottom:top catch ratio across the remaining sample dates was 6.5:1 in the cantaloupe and 3.6:1 in the watermelon field. Furthermore, there was also a difference between *Eretmocer* sexes in their tendency to be trapped on lower versus upper trap surfaces, with females being nearly twice as likely as males to be trapped on the lower surface. Exotic *E. emiratus* far outnumbered native *E. eremicus* and *Encarsia* spp. on the traps at these two sites, by ratios of 20.5 exotics per native in cantaloupe and 26.8 exotics per native in watermelon. Females were trapped in significantly greater numbers than males in each field. The ratio of females to males on traps increased during the 7-wk sampling period, beginning as male-biased, but ending up female-biased. Summed across all sample dates the ratio was 1.33:1 female:male.

Throughout the season, the trend of increasing numbers of *Eretmocer* on traps generally followed the trend of increasing numbers of *Eretmocer*-parasitized whiteflies counted on leaf samples in cantaloupe but not in watermelon (Fig. 3). Trap numbers and parasitized fourth-instar whiteflies on leaf samples were not, however, significantly correlated in cantaloupe (Pearson's $R^2 = 0.57$, $P = 0.19$), nor were they

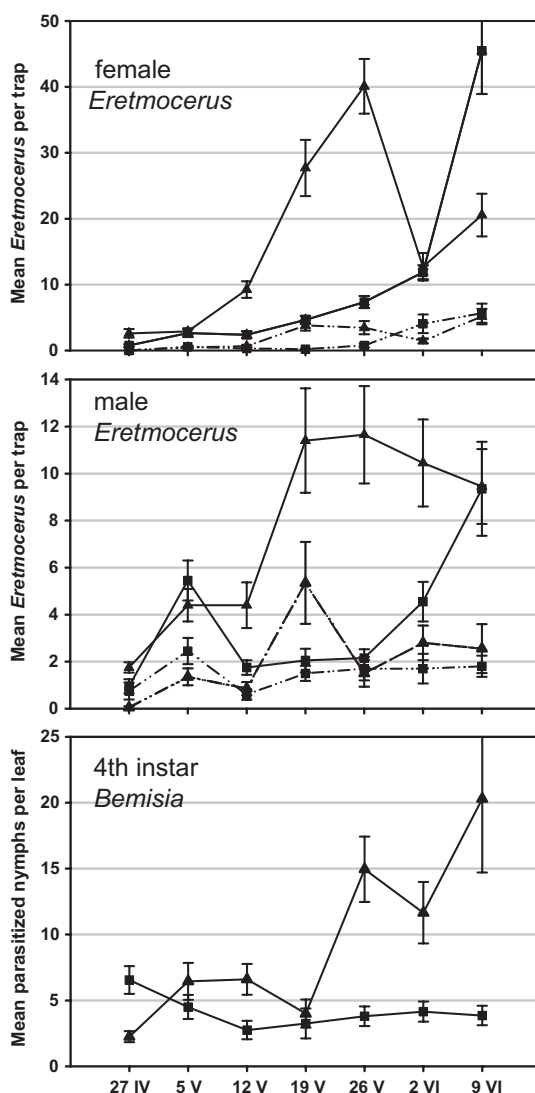


Fig. 2. Mean numbers (\pm SEM) of adult female and male *Eretmocer* caught on yellow sticky traps in cantaloupe (\blacktriangle) and watermelon (\blacksquare) fields, Imperial Valley, CA, in spring of 1998. Catches on upper (dashed line) and lower (solid line) trap surfaces are shown separately. Mean number (\pm SEM) of parasitized fourth instars per leaf from associated leaf samples is shown at bottom for comparison.

correlated in watermelon ($R^2 = -0.22$, $P = 0.63$), where whitefly numbers were much lower than in cantaloupe. Throughout the 7-wk sample period, a large proportion (0.23–0.84) of all fourth instars on leaf samples were visibly parasitized by *Eretmocer*; the mean proportion of parasitism across all 7 wk was 0.39 ± 0.040 (SEM) in cantaloupe and 0.57 ± 0.066 in watermelon. This estimate included parasitism by young *Eretmocer* larvae and unhatched eggs found when turning over whitefly nymphs. Counts of adults on traps were also out of phase with estimates of

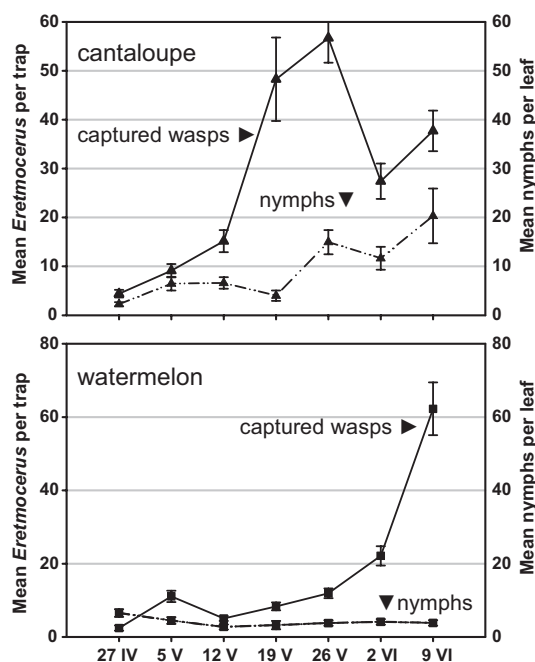


Fig. 3. Mean numbers (\pm SEM) of *Eretmocerus* (sexes and species summed) captured on upper and lower surfaces of yellow sticky traps (solid line) versus mean number (\pm SEM) of whitefly nymphs parasitized by *Eretmocerus* on leaf samples (dashed line), Imperial Valley, CA.

immature parasitoids within whiteflies on leaves, because the latter were the progeny of adult females that searched several weeks earlier, whereas any progeny of the former would not be reflected in leaf samples for several additional weeks. We therefore also looked for correlations between trap catches of 1 week and leaf counts the following week (in cantaloupe: Pearson's $R^2 = 0.22$, $P = 0.67$; in watermelon: $R^2 = -0.05$, $P = 0.93$) and 2 weeks later (in cantaloupe: Pearson's $R^2 = 0.32$, $P = 0.60$; in watermelon: $R^2 = -0.50$, $P = 0.39$), but there were no correlations. Voucher samples of parasitoids reared from parasitized whitefly on the leaf samples taken on seven dates in May and June 1998 were identified to species. The majority of *Eretmocerus* voucher specimens were exotic *E. emiratus* (93% in cantaloupe, $n = 100$, and 90% in watermelon, $n = 111$), which must have been progeny of the releases made in these fields, because at the time of this study, this species had not yet become established widely in the region, as shown by surveys outside of the study site (K.A.H., unpublished data). The sex ratio of *E. emiratus* reared in these voucher samples was biased slightly in favor of females (54.8% in cantaloupe, 52.6% in watermelon), which was less than the overall female bias observed in the sticky trap catches.

Only a small proportion of whitefly parasitism in the leaf samples was caused by native *Encarsia* species (2.9% in cantaloupe and 7.5% in watermelon of voucher specimens reared); these appeared only during the first weeks' rearings early in the season.

Similarly, *Encarsia* species were trapped only in very low numbers by the sticky traps. Two species, *Encarsia luteola* Howard and *E. meritoria* Gahan, attack *Bemisia* in Imperial Valley. The mean number of both sexes of these species combined never exceeded 0.1 per card and was zero for most sample dates (data not shown). Therefore, nearly all of the parasitism in the cantaloupe and watermelon leaf samples was caused by introduced and indigenous *Eretmocerus* species.

Collard and Cowpea, Charleston, SC. Numbers of whiteflies and parasitoids captured on collard were low in 1997. Few leaves contained immature whiteflies. The number of *B. tabaci* nymphs on the collard leaf samples ranged from 1 to 43 per sample date. The trend in numbers generally declined from late September to early January 1998 (Fig. 4). Higher numbers of whiteflies were captured than the parasitoids, although there was overall good fidelity between capture of the host and parasitoids ($r^2 = 0.45$, $P < 0.001$). The proportion of parasitism from leaf samples (the ratio of parasitoids to total whiteflies and parasitoids emerged) is shown (minus several weeks of missing data from samples which deteriorated and could not be counted) and only corresponded in one field (8LW, $r^2 = 0.42$, $P < 0.038$) to the proportion of trapped parasitoids to trapped whiteflies. Late in the season when numbers were lowest, there may have been a disproportionate influence of low numbers of parasitoids. Similarly, more whiteflies than parasitoids were captured in the cowpea fields (Fig. 5) in 1998. The number of *B. tabaci* nymphs on the cowpea leaf samples ranged from 7 to 112 per sample date. More whiteflies and parasitoids were trapped in field 8LW compared with field 2F. Some of the leaf samples were lost, but those dates for which percent parasitism was obtained are indicated in Figs. 4 and 5. No correlations were observed between numbers of parasitoids captured on traps and numbers of parasitized whiteflies on leaves for either of these two crops ($P > 0.05$ in each field).

In cowpea, peak captures of the parasitoids occurred in mid-to-late August and late August to early October in 1998. More parasitoids were captured ($F = 8.96$, $P < 0.01$), and the ratio of parasitoid to whitefly capture was lower ($F = 11.03$, $P < 0.01$) in field 8LW than field 2F. Parasitism was $\sim 50\%$ from mid-September to mid-October, the only other period for which parasitism data were available (Fig. 5). During that time, parasitism was the same ($F = 1.96$, $P > 0.05$) for both fields. Overall, $\sim 89\%$ of the parasitoids captured in each cowpea field in 1998 were *Eretmocerus* sp., whereas $\sim 7\%$ were *E. pergandiella*, and the others were an unidentified *Encarsia* species. In 1997, $\sim 83\%$ of the parasitoids captured in collard were *Eretmocerus* sp., whereas *E. pergandiella* consisted of $\sim 17\%$, and the remaining parasitoids consisted of $< 1\%$ of other *Encarsia* species.

Incidence of Capture in the Laboratory. In the laboratory comparisons of trap capture (Table 1), there were no significant differences in capture between females of *E. pergandiella* and *Eretmocerus*

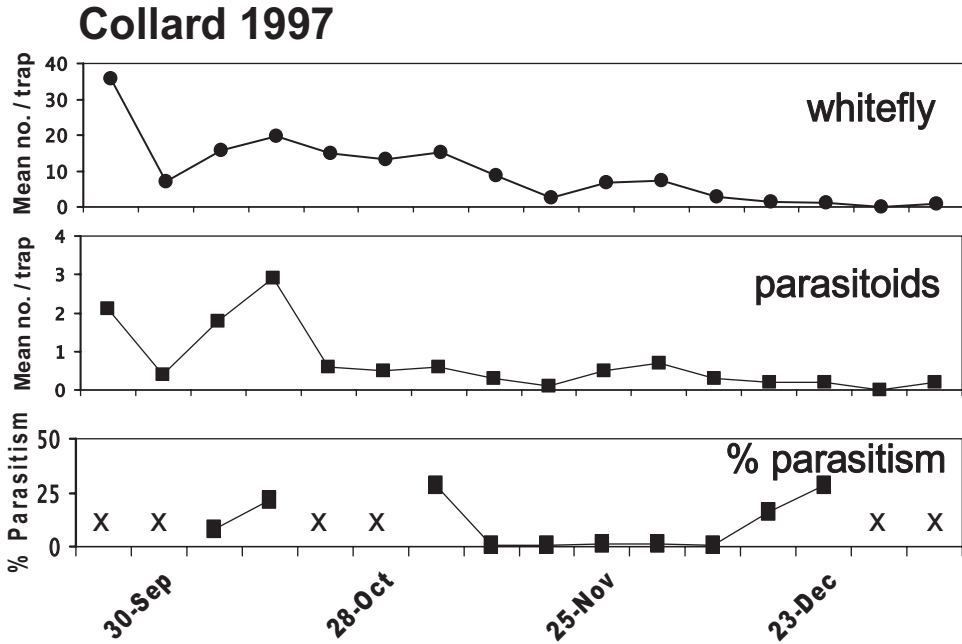


Fig. 4. Mean numbers of adult *B. tabaci* and its parasitoids caught on yellow sticky traps in a collard field and percent parasitism on associated leaf samples, Charleston, SC, in fall of 1997. The number of *B. tabaci* nymphs on leaf samples ranged from 1 to 43 over the dates sampled. X denotes dates with no percent parasitism data.

sp. ($P > 0.05$, $df = 12$, $t = 2.17$). Significantly more male than female *Eretmocerus* ($P < 0.001$, $df = 60$, $t = -5.18$) were captured on the yellow sticky cards ($50.0 \pm 2.8\%$ of the males were captured versus $31.6 \pm 2.1\%$ of the females). However, whitefly females were captured more frequently ($P < 0.0001$,

$df = 34$, $t = -14.11$) than the *Eretmocerus* sp. females, with $81.7 \pm 1.8\%$ of the whiteflies and $40.8 \pm 2.3\%$ of *Eretmocerus* caught on traps. In a fourth comparison, there was no difference in capture between female versus male *B. tabaci* ($P > 0.05$, $df = 22$, $t = 1.44$).

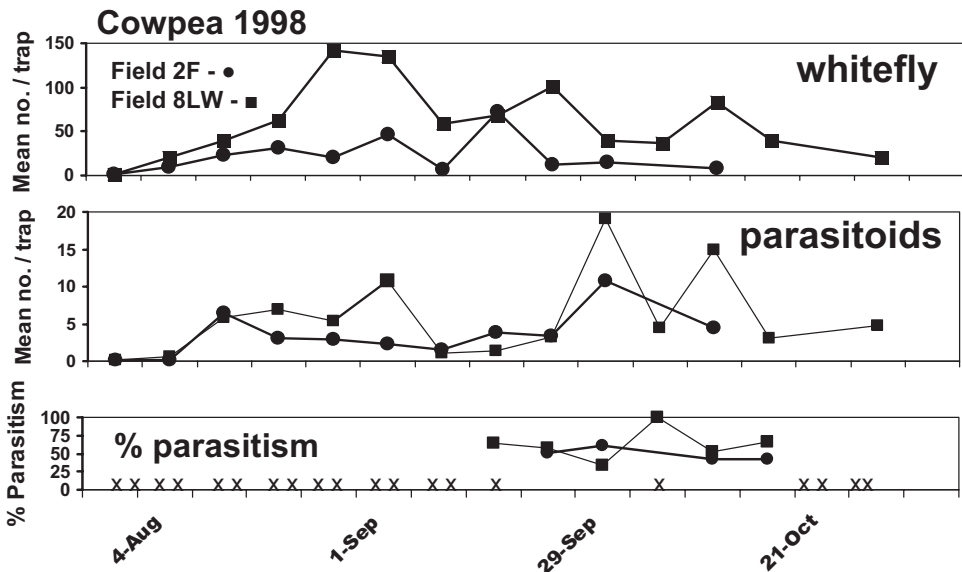


Fig. 5. Mean numbers of adult *B. tabaci* and its parasitoids caught on yellow sticky traps in two cowpea fields and percent parasitism on associated leaf samples, Charleston, SC, in 1998. Numbers of *B. tabaci* nymphs on leaf samples ranged from 7 to 112 over the dates sampled. X denotes dates with no percent parasitism data for one or both fields.

Table 1. Relative attraction of *Bemisia tabaci* and parasitoids to yellow sticky cards in paired laboratory tests (25 °C)

Test	No. of insects	Genus ^a	Sex	Mean % capture (±SEM) ^b
1	140	<i>Encarsia</i>	Female	45.7 ± 3.7a
	140	<i>Eretmocer</i>	Female	30.0 ± 6.5a
2	620	<i>Eretmocer</i>	Female	31.6 ± 2.1b
	620	<i>Eretmocer</i>	Male	50.0 ± 2.8a
3	360	<i>Eretmocer</i>	Female	40.8 ± 2.3b
	360	<i>Bemisia</i>	Female	81.7 ± 1.8a
4	240	<i>Bemisia</i>	Female	86.3 ± 3.8a
	240	<i>Bemisia</i>	Male	80.0 ± 2.9a

^a *Encarsia pergandiella*, *Eretmocer* sp., and *Bemisia tabaci* biotype B.

^b Means within a test and followed by different letters are significantly different ($P < 0.05$) according to the Student *t*-test (SAS 2002).

Discussion

The preponderance of *E. emiratus* on the lower surfaces of traps at the melon field sites suggests that most of the movement by *Eretmocer* occurred very close to the ground. It is reasonable to suppose that predominantly local movement among and between vines would take place close to the ground. If so, this further suggests that most of the parasitoids trapped probably originated within the study fields, rather than migrating into the fields from elsewhere. Otherwise, a larger proportion would have been trapped on the upper surface instead of the lower surface. Height of yellow sticky traps was also reported to affect incidence of capture of parasitoids of *B. tabaci* in tomato (Qiu and Ren 2006). In that report, traps which were maintained at 30 cm above the canopy captured fewer *Eretmocer* and *Encarsia* spp. than traps maintained at the same level as the top of the tomato plants. Because the proportion of females and males emerging from our leaf samples was very different from the proportion found on the sticky traps, there may have been a greater tendency for females to be trapped because of behavioral differences between the sexes.

More research is needed to determine whether a significant correlation could be obtained by increasing the total surface area of traps relative to the area of infested leaves containing the appropriate stages of whitefly. Moreover, because yellow sticky traps are known to be highly attractive to whiteflies, when in-field populations of whiteflies are low, the traps may have a disproportionate impact on numbers of whiteflies trapped compared with parasitoids. In a related laboratory trap study, but using yellow sticky card sections in petri dishes, Simmons (1998) reported that *B. tabaci* (as *B. argentifolii*) adults were captured ≈1.3 times more frequently than *E. pergandiella*. Those data and data herein suggest that there is a slightly greater propensity for the whitefly to be attracted to the yellow sticky cards than either of these parasitoid species. Parasitoid searching activity may be related to capture. Webb and Smith (1980) and van de Veire and Vacante (1984) reported increased trap catches of the parasitoid *E. formosa* in greenhouses as unparasitized

nymphs of its host, *Trialetrodes vaporariorum* (Westwood), decreased in number, and they suggested that increased searching was responsible.

The laboratory data pertaining to the native *Eretmocer* sp. in South Carolina suggest that males have a slightly greater propensity for being attracted to yellow than females. Conversely, in our field study in the cantaloupe and watermelon, females of exotic *E. emiratus* and native *E. eremicus* were more abundant than males on both upper and lower trap surfaces. In another field study in cotton, Hoelmer et al. (1998) reported that a greater number of male than female *E. eremicus* were captured on only one of four sampling dates, with females predominating on the other dates. However, the sex ratio was not measured in these field populations by using another sampling method for comparison, such as rearing parasitized whiteflies on leaf samples, and variable environmental conditions in the field during the course of the study may have influenced trap catches. This unexplained discrepancy could be because of unknown behavioral differences between the two *Eretmocer* species or the conditions of exposure to the traps, which may be significantly different in the field than in the laboratory tests with respect to the parasitoid behavior(s) responsible. Recent flight chamber and field studies suggest that dispersal by *E. eremicus* may result from behavioral differences between the sexes. Bellamy and Byrne (2001) reported that, in the laboratory, mated and unmated females flew longer than their male counterparts, but more males (87%) than females were captured in fan traps in the field. Blackmer and Cross (2001) reported that females were more attracted to plant cues than males and suggested that females are driven to locate hosts in which to oviposit and males are driven to find mates.

The capture of adult whiteflies and parasitoids is strongly influenced by environmental conditions and other factors affecting population dynamics such as mortality, emergence, and overall abundance (Gerling and Horowitz 1984, Ohnesorge and Rapp 1986, Simmons 1998, Simmons and Elsey 1995, Simmons and Jackson 2000, Simmons et al. 2002). The abundance of *B. tabaci* (as *B. argentifolii*) and associated parasitoids, based on sticky card capture, previously (1994–1996) differed between the two cowpea fields (Simmons and Jackson 2000) at the South Carolina location. It is not uncommon for different numbers of whiteflies and parasitoids to be captured during different times of the growing season and at different locations in South Carolina (Simmons 1998). Moreover, previous research reported that relatively low numbers of *Bemisia* were captured during the mild but cooler months in coastal South Carolina (Simmons and Elsey 1995). The trend in numbers of adult *Eretmocer* caught by yellow sticky traps was similar to the trend in parasitized whiteflies based on leaf samples in the cantaloupe field, but less similar in the watermelon field. Correlating the numbers on traps to estimates of *Eretmocer* populations provided by parasitism on leaf samples was not achieved. Such a correlation should be possible, but further studies relating num-

bers of traps, trap surface area, and placement to other measures of population size are needed. However, our results suggest that sticky traps placed within crops may nevertheless be helpful in (1) monitoring general trends in whitefly parasitoid populations and activity at sites and (2) detecting the presence of these parasitoids at specific locations, for example, in surveys to document establishment. Additional research on the flight behavior of whitefly parasitoids and their response to environmental factors may also be helpful in further interpretation of sticky trap results.

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